

Measurement of charmless B Decays to ηK^* and $\eta\rho$

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Abstract

We report branching fractions and CP asymmetries for $B \rightarrow \eta K^*$ and $B \rightarrow \eta \rho$ decays. These results are obtained from a 414fb^{-1} data sample collected at the $\Upsilon(4S)$ resonance, with the Belle detector at the KEKB asymmetric energy e^+e^- collider. The branching fractions, in parts per million, of ηK^{*0} , ηK^{*+} , $\eta \rho^0$, and $\eta \rho^+$ are $15.9 \pm 1.2 \pm 0.9$, $19.7_{-1.9}^{+2.0} \pm 1.4$, $0.84_{-0.51}^{+0.56} \pm 0.18$, and $4.1_{-1.3}^{+1.4} \pm 0.34$, respectively. We find no evidence for CP asymmetries in these modes.

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INTRODUCTION

Charmless hadronic B decays play an important role in understanding CP violation in the B meson system. Studies of $B \rightarrow \eta K^*$ and $B \rightarrow \eta \rho$ [1] are important examples of such decays. In the standard model (SM), Penguin (tree) diagrams are expected to dominate in $B \rightarrow \eta K^*$ ($B \rightarrow \eta \rho$) decays. The large branching fraction for $B \rightarrow \eta K^*$ compared to that for $B \rightarrow \eta K$ decay [2, 3, 4] can be explained qualitatively in terms of the interference between non-strange and strange components of the η meson, but are higher than recent theoretical predictions [5, 6, 7, 8]. In a similar vein, the larger measured branching fraction for charged ($B^+ \rightarrow \eta K^{*+}$) vs. neutral ($B^0 \rightarrow \eta K^{*0}$) decays may suggest an additional SU(3)-singlet contribution [7, 8, 9] or constructive interference between SM penguin and tree amplitudes or between SM- and New Physics(NP)-penguin amplitudes.

In the standard model, direct CP violation (DCPV) occurs in decays that involve two (or more) amplitudes that have different CP conserving and CP violating phases. The partial rate asymmetry can be written as

$$\mathcal{A}_{CP}(B \rightarrow f) = \frac{\Gamma(\bar{B} \rightarrow \bar{f}) - \Gamma(B \rightarrow f)}{\Gamma(\bar{B} \rightarrow \bar{f}) + \Gamma(B \rightarrow f)} = \frac{2|A_1||A_2| \sin \Delta\delta \sin \Delta\phi}{|A_1|^2 + |A_2|^2 + 2|A_1||A_2| \cos \Delta\delta \cos \Delta\phi}, \quad (1)$$

where f denotes a self-tagging final state, B is either B^+ or B^0 meson, \bar{B} and \bar{f} are the conjugate states, and $\Delta\delta$ ($\Delta\phi$) is the difference of the CP-conserving (CP-violating) phases between amplitudes A_1 and A_2 . The charge asymmetry will be sizeable when the two amplitudes are of comparable strength with significant phase differences. SM Penguin diagrams are expected to dominate in the $B \rightarrow \eta K^*$ decays, while tree diagrams are expected to dominate in $B^+ \rightarrow \eta \rho^+$ decays. Therefore, DCPV in both cases should be small. However, SM- and NP-penguin diagrams may interfere to generate sizable direct CP violation.

DATA SET AND APPARATUS

This analysis is based on a data sample collected at the $\Upsilon(4S)$ resonance with the Belle detector [10] at the KEKB [11] accelerator. The data sample corresponds to an integrated luminosity of 414 fb^{-1} and contains 449×10^6 $B\bar{B}$ pairs.

The Belle detector is designed to measure charged particles and photons with high efficiency and precision. Charged particle tracking is provided by a silicon vertex detector (SVD) and a central drift chamber (CDC) that surround the interaction region. The charged particle acceptance covers the laboratory polar angle between $\theta = 17^\circ$ and 150° , measured from the z axis that is aligned anti-parallel to the positron beam. Charged hadrons are distinguished by combining the responses from an array of silica aerogel Cherenkov counters (ACC), a barrel-like array of 128 time-of-flight scintillation counters (TOF), and dE/dx measurements in the CDC. The combined response provides K/π separation of at least 2.5σ for laboratory momentum up to 3.5 GeV/c. Electromagnetic showers are detected in an array of 8736 CsI(Tl) crystals (ECL) located inside the magnetic volume, which cover the same solid angle as the charged particle tracking system. The 1.5-T magnetic field is contained via a flux return that consists of 4.7 cm thick steel plates, interleaved with resistive plate counters used for tracking muons. Two inner detector configurations are used. A 2.0 cm beampipe and a 3-layer silicon vertex detector are used for the first sample of 152×10^6 $B\bar{B}$ pairs, while a 1.5 cm beampipe, a 4-layer silicon detector and a small-cell inner drift chamber are used to record the remaining 297×10^6 $B\bar{B}$ pairs [12].

For Monte Carlo (MC) simulation study, the signal events, generic $b \rightarrow c$ decays and charmless rare B decays are generated with the EVTGEN [13] event generator. The continuum MC events are generated with the $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q}$ process in the JETSET generator. The GEANT3 [14] package is used for detector simulation.

EVENT SELECTION AND RECONSTRUCTION

Hadronic events are selected based on the charged track multiplicity and total visible energy sum, which give an efficiency greater than 99% for $B\bar{B}$ events. All primary charged tracks are required to satisfy track quality cuts based on their impact parameters relative to the run-dependent interaction point (IP): within ± 2 cm along the z axis and within ± 1.5 cm in the transverse plane. Particle identification (PID) is based on the likelihoods $\mathcal{L}_K/(\mathcal{L}_\pi + L_K)$ for charged kaons and pions, respectively. A higher value of $\mathcal{L}_K/(\mathcal{L}_\pi + L_K)$ indicates a more kaon-like particle. PID cuts are applied to all charged particles except pions from K_S^0 in this analysis. Unless explicitly specified, the PID cuts are $\mathcal{L}_K/(\mathcal{L}_\pi + L_K) > 0.6$ for kaons and < 0.4 for pions. The PID efficiencies are 85% for kaons and 89% for pions, while the fake rates are 8% for pions faking kaons and 11% for kaons faking pions. In forming π^0 candidates from photon pairs, the photon energies must exceed 50 MeV and the π^0 momentum in the center of mass (CM) frame must exceed 0.35 GeV/ c . K_S^0 candidates are reconstructed from pairs of oppositely charged tracks whose invariant mass lies within ± 10 MeV/ c^2 of the K_S^0 meson mass. We also require the vertex of the K_S^0 to be well reconstructed and displaced from the interaction point, and the K_S^0 momentum direction be consistent with the K_S^0 flight direction.

η Meson Reconstruction

Candidate η mesons are reconstructed through $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$. If one of the photons from the former η decay mode could be paired with another photon with reconstructed $\gamma\gamma$ mass within 3σ of the π^0 meson mass, then the η candidate is discarded. We relax the PID requirement for charged pions from the latter η decay mode to $\mathcal{L}_K/(\mathcal{L}_\pi + L_K) < 0.9$. The momenta of the η candidate is recalculated by applying the η mass constraint for B reconstruction. The $\eta \rightarrow \gamma\gamma$ candidates must satisfy $|\cos\theta^*| < 0.90$, where θ^* is the angle between the photon direction in the η rest frame and the η momentum in the CM frame, so as to suppress the soft photon combinatorial background and $B \rightarrow K^*\gamma$ feed-across. The reconstructed mass resolutions are 12 MeV/ c^2 for $\eta \rightarrow \gamma\gamma$ and 3.5 MeV/ c^2 for $\eta \rightarrow \pi^+\pi^-\pi^0$.

K^*, ρ Meson Reconstruction

K^{*0} candidates are reconstructed from $K^-\pi^+$ and $K_S^0\pi^0$ pairs, while K^{*+} mesons are reconstructed from $K^+\pi^0$ and $K_S^0\pi^+$ pairs. Candidate K^* mesons are required to have reconstructed masses within ± 75 MeV/ c^2 of the nominal value. Candidate ρ^0 (ρ^+) mesons are reconstructed from $\pi^-\pi^+$ ($\pi^0\pi^+$) pairs. Each combination is required to have a reconstructed mass within ± 150 MeV/ c^2 of the nominal value.

B Meson Reconstruction

B meson candidates are reconstructed from ηK^{*0} , ηK^{*+} , $\eta \rho^0$, and $\eta \rho^+$ combinations. They are characterized by the beam-constrained mass $M_{bc} = \sqrt{E_{\text{beam}}^2 - |P_B|^2}$ and the energy difference $\Delta E = E_B - E_{\text{beam}}$, where $E_{\text{beam}} = 5.29$ GeV, and P_B and E_B are the momentum and energy, respectively, of B candidate in the $\Upsilon(4S)$ rest frame. We define the fit region in the M_{bc} - ΔE plane as $M_{bc} > 5.2$ GeV/ c^2 and $|\Delta E| < 0.25$ GeV. We define the signal region as the overlap of the bands $M_{bc} > 5.27$ GeV/ c^2 and $|\Delta E| < 0.05$ GeV.

One candidate per event is required for all modes. The best candidate is chosen based on the sum of η vertex mass constraint fit χ^2 and $K^{*0}(\rho^0)$ vertex χ^2 for $B \rightarrow \eta K^{*0}$, $K^{*0} \rightarrow K^+ \pi^-$ and $B \rightarrow \eta \rho^0$. For the $B^+ \rightarrow \eta K^{*+}$, $K^{*+} \rightarrow K^0 \pi^+$ mode, the reconstructed K^{*+} mass χ^2 and the η vertex mass constraint fit χ^2 are used. For the remaining modes, the χ^2 values of the η and π^0 mass constraint fits are used.

BACKGROUND SUPPRESSION

The dominant background for exclusive two-body B decays comes from the $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q}$ continuum ($q = u, d, s, c$), which has a jet-like event topology compared to the spherical $B\bar{B}$ events. Other major backgrounds involve feed-across from other charmless B decays. For decays involving the ρ meson, an additional background arises from $b \rightarrow c$ decays. However, the impact of this background is small since the M_{bc} and ΔE distributions do not peak in the signal region.

Continuum Background

Signal and continuum events are distinguished by two means. First, we require $|\cos \theta_T| < 0.9$, where θ_T is defined as the angle between the η daughter of a B candidate and the thrust axis from all the particles in the event not associated with that B candidate. This retains 90% of signal and removes $\sim 56\%$ of continuum. Second, a probability density function \mathcal{L}_s (\mathcal{L}_c) for signal (continuum) is formed from two independent variables— $\cos \theta_B$, where θ_B is the polar angle of the B candidate, and a Fisher discriminant [15] $\mathcal{F} = \vec{\alpha} \cdot \vec{R}$ that combines seven event shape variables: $\cos \theta_T$, S_\perp (the scalar sum of the transverse momenta of all particles outside a 45° cone around the B candidate direction divided by the scalar sum of the momenta), and the five modified Fox-Wolfram moments [16] R_2^{so} , R_4^{so} , R_2^{oo} , R_3^{oo} , and R_4^{oo} . The Fisher discriminant's weight vector $\vec{\alpha}$ is determined by optimizing the separation between signal events and continuum background using MC data; these Fox-Wolfram moments are used since they are not correlated with M_{bc} . The likelihood ratio $\mathcal{LR} = \mathcal{L}_s/(\mathcal{L}_s + \mathcal{L}_c)$ is used to distinguish signal from continuum, since it peaks near 1 for signal and near 0 for continuum.

The distribution of \mathcal{LR} is found to depend somewhat on the event's B flavor tagging quality parameter r [17], which ranges from zero for no flavor identification to unity for unambiguous flavor assignment. We partition the data into three r regions, and determine the optimal cut on \mathcal{LR} in each region by maximizing the significance $N_S/\sqrt{N_S + N_B}$ formed from the retained number of signal (N_S) and continuum background (N_B) events in MC samples. A typical cut of $\mathcal{LR} > 0.5$ is $\sim 75\%$ efficient for signal and removes $\sim 81\%$ of the

continuum background, while $\mathcal{LR} > 0.9$ is $\sim 38\%$ efficient for signal and removes $\sim 97\%$ of the continuum background.

Feed-across and $b \rightarrow c$ Backgrounds

A $B \rightarrow K^*(\rho)\gamma$ veto is applied to suppress the $K^*(\rho)\gamma$ feed-down for $B \rightarrow \eta K^*(\rho)$, $\eta \rightarrow \gamma\gamma$ decays. The MC studies show that the background from $b \rightarrow c$ decays and the feed-across from other charmless B decays are negligible for $B \rightarrow \eta K^*$ decays. For $B \rightarrow \eta\rho$ decays, the background can be as large as 4% of the total yield (Table I). The contributions of these backgrounds are taken into account in the analysis.

TABLE I: Estimated yields from $b \rightarrow c$ (N_{bc}), charmless B decay (N_r) backgrounds, ηK^* feed-across (N_{feed}) and actual yields from all sources (N) after the $\cos\theta_T$ and \mathcal{LR} cuts.

Mode	N_{bc}	N_r	N_{feed}	N
$\eta_{\gamma\gamma}\rho^0$	62	81	17	2931
$\eta_{\pi\pi\pi^0}\rho^0$	67	27	5	1063
$\eta_{\gamma\gamma}\rho^+$	148	74	3	4169
$\eta_{\pi\pi\pi^0}\rho^+$	76	22	1	1809

ANALYSIS PROCEDURE

Signal yields are obtained using an extended unbinned maximum likelihood (2-D ML) fit to the M_{bc} and ΔE distributions in the M_{bc} - ΔE fit region that satisfy the $\cos\theta_T$ and \mathcal{LR} requirements.

For N input candidates, the likelihood is defined as

$$L(N_S, N_B) = \frac{e^{-(N_S + N_B + N_{bc} + N_r + N_{\text{feed}})}}{N!} \prod_{i=1}^N [N_S P_{S_i} + N_B P_{B_i} + N_{bc} P_{bc_i} + N_r P_{r_i} + N_{\text{feed}} P_{\text{feed}_i}] (2)$$

where P_{S_i} , P_{B_i} , P_{bc_i} , P_{r_i} and P_{feed_i} are the probability densities for event i to be the signal, continuum, $b \rightarrow c$, charmless B decay and feed-across backgrounds for variables M_{bc} and ΔE , respectively. Poisson statistics for N_S and N_B , the extracted yields for the signal and continuum background from the fit, are considered in this type of likelihood L . The yields N_{bc} , N_r , and N_{feed} are fixed from the MC analysis.

The continuum, $b \rightarrow c$ and charmless B-decay background ΔE PDF's are modeled by higher order polynomial functions. The continuum and $b \rightarrow c$ background components in M_{bc} are modeled by a smooth function [18]. Due to the peaking behavior of M_{bc} in the signal region from charmless B decay backgrounds, we use a sum of two bifurcated-Gaussian functions to model the distributions. The bifurcated Gaussian combines the left half of a wide-resolution Gaussian with the right half of a narrow-resolution Gaussian, both having a common mean. For $B \rightarrow \eta\rho$ decays, M_{bc} and ΔE distributions from ηK^* feed-across will behave like signal with a ΔE shift of -50 MeV. The PDF shape for each contributions

is determined by MC. The slope of the continuum-background ΔE polynomial and the parameters of the M_{bc} function are allowed to float in each fit.

For signal ΔE , we used two bifurcated-Gaussian functions. The first accounts for 60-80% of the total area and the second, which has a larger width, is used to model the low-energy tail. M_{bc} is weakly correlated with ΔE , so we construct separate bifurcated Gaussians for M_{bc} in the three ranges $|\Delta E| < 0.05$ GeV, $0.05 \text{ GeV} < |\Delta E| < 0.1$ GeV, and $0.1 \text{ GeV} < |\Delta E| < 0.25$ GeV.

For decays with more than one sub-decay process, the final results are obtained by fitting the sub-decay modes simultaneously with the expected efficiencies folded in and with the branching fraction as the common output. This is equivalent to summing $\chi^2 = -2 \ln(L)$ as a function of the branching fraction for the sub-decay channels. The statistical significance (Σ) of the signal is defined as $\sqrt{-2 \ln(L_0/L_{\max})}$, where L_0 and L_{\max} denote the likelihood values at zero signal events and the best fit numbers, respectively.

The 90% confidence level (C.L.) upper limit x_{90} is calculated from the equation:

$$\frac{\int_0^{x_{90}} L(x) dx}{\int_0^\infty L(x) dx} = 90\% . \quad (3)$$

For this calculation of x_{90} , the likelihood function is modified to incorporate the systematic uncertainty.

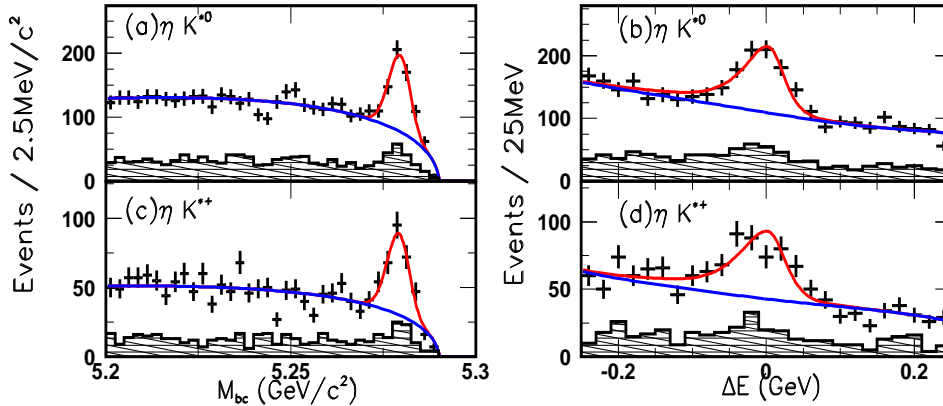


FIG. 1: Projections on M_{bc} (for the signal slice in ΔE) and ΔE (for the signal slice in M_{bc}) for ηK^{*0} (a,b) and ηK^{**} (c,d) with the expected signal and background function overlaid. The shaded area represents $\eta \rightarrow \pi^+\pi^-\pi^0$ decays.

MEASUREMENTS OF BRANCHING FRACTIONS

The overall reconstruction efficiency ϵ is first obtained using MC samples and then multiplied by PID efficiency corrections obtained from data. The PID efficiency correction is determined by using $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$ data samples.

TABLE II: Summary of results for each channel listed in the first column. The measured signal yield (N_S), statistical significance (Σ), reconstruction efficiency (ϵ), total efficiency (ϵ_{tot}) including the secondary branching fraction, and measured branching fractions are shown. Uncertainties shown in second and sixth columns are statistical only. The upper limit for $\eta\rho^0$ is at 90% C.L.

Mode	N_S	$\epsilon(\%)$	$\epsilon_{tot}(\%)$	Σ	$\mathcal{B}(10^{-6})$
$\eta\gamma\gamma K_{K^+\pi^-}^{*0}$	$336.2^{+30.1}_{-29.2}$	16.9	4.4	14.2	$16.9^{+1.5}_{-0.9}$
$\eta\pi\pi\pi^0 K_{K^+\pi^-}^{*0}$	$93.4^{+14.6}_{-13.8}$	9.8	1.5	8.7	$14.1^{+2.2}_{-2.1}$
$\eta\gamma\gamma K_{K^0\pi^0}^{*0}$	$20.1^{+7.5}_{-6.7}$	2.1	0.27	3.6	$16.7^{+6.3}_{-5.6}$
$\eta\pi\pi\pi^0 K_{K^0\pi^0}^{*0}$	$9.5^{+5.0}_{-4.2}$	1.3	0.098	2.6	$21.6^{+11.5}_{-9.7}$
ηK^{*0}	-	-	-	17.1	16.1 ± 1.2
$\eta\gamma\gamma K_{K^+\pi^0}^{*+}$	$79.8^{+16.1}_{-15.3}$	6.7	0.88	6.1	$20.1^{+4.1}_{-3.9}$
$\eta\pi\pi\pi^0 K_{K^+\pi^0}^{*+}$	$24.1^{+8.7}_{-7.9}$	4.2	0.32	3.5	$17.0^{+6.1}_{-5.6}$
$\eta\gamma\gamma K_{K^0\pi^+}^{*+}$	$120.3^{+16.2}_{-15.4}$	4.5	1.2	10.1	$22.6^{+3.1}_{-2.9}$
$\eta\pi\pi\pi^0 K_{K^0\pi^+}^{*+}$	$29.2^{+7.3}_{-6.6}$	2.6	0.38	6.2	$17.0^{+4.8}_{-3.8}$
ηK^{*+}	-	-	-	13.8	$20.3^{+2.0}_{-1.9}$
$\eta\gamma\gamma\rho^0$	$19.5^{+11.3}_{-10.4}$	8.9	3.5	2.1	$1.25^{+0.73}_{-0.67}$
$\eta\pi\pi\pi^0\rho^0$	$0.9^{+4.6}_{-3.9}$	5.5	1.2	0.2	$0.17^{+0.84}_{-0.66}$
$\eta\rho^0$	-	-	-	1.6	$0.84^{+0.56}_{-0.51} (< 1.5)$
$\eta\gamma\gamma\rho^+$	$38.1^{+16.1}_{-15.2}$	5.5	2.2	2.6	$3.9^{+1.7}_{-1.6}$
$\eta\pi\pi\pi^0\rho^+$	$15.8^{+8.9}_{-8.0}$	3.50	0.79	2.1	$4.4^{+2.5}_{-2.2}$
$\eta\rho^+$	-	-	-	3.4	$4.1^{+1.4}_{-1.3}$

Other MC efficiency corrections are determined by comparing data and MC predictions of other well-known processes. The charged tracking efficiency correction is studied using a high-momentum η sample, comparing the ratio of $\eta \rightarrow \pi^+\pi^-\pi^0$ to $\eta \rightarrow \gamma\gamma$ between data and MC. The same high-momentum η sample is also used for π^0 reconstruction efficiency corrections by comparing the ratio of $\eta \rightarrow \pi^0\pi^0\pi^0$ to $\eta \rightarrow \gamma\gamma$ between the data and MC sample. The K_S^0 reconstruction efficiency is verified by comparing four $K^*(892)$ decay channels ($K^+\pi^-$, $K^+\pi^0$, $K_S^0\pi^+$, $K_S^0\pi^0$) in inclusive K^* and exclusive $B \rightarrow J/\psi K^*$ samples. The \mathcal{LR} cut efficiency correction is determined using $B \rightarrow D\pi^+$ decays. For η and K^* reconstruction and mass cuts, we use the high-momentum η and K^* sample for the efficiency correction studies.

The above studies show good agreement between the efficiencies in the data and MC sample at about the 2% level. The PID, π^0 , η and K^* reconstruction efficiency corrections are applied and the systematic uncertainties are also obtained from the above studies.

The fitted signal yields and branching fractions are shown in Table II. Several consistency checks are made, including tighter \mathcal{LR} cuts, 1-D ML M_{bc} , and ΔE fits, and they are all shown to be consistent. The total observed yields from the fits, with all sub-decay modes combined, are $N_{\eta K^{*0}} = 459.2^{+34.6}_{-33.3}$ for $B^0 \rightarrow \eta K^{*0}$, $N_{\eta K^{*+}} = 253.4^{+25.5}_{-24.0}$ for $B^+ \rightarrow \eta K^{*+}$, $N_{\eta\rho^0} = 20.4^{+12.2}_{-11.0}$ for $B^0 \rightarrow \eta\rho^0$ and $N_{\eta\rho^+} = 53.9^{+18.4}_{-17.1}$ for $B^+ \rightarrow \eta\rho^+$. Figure 1 shows the projections of the data and the fits onto M_{bc} (for events in ΔE signal slice) and ΔE (for events in the M_{bc} signal slice) for the $B \rightarrow \eta K^*$ decays, while Fig. 2 shows the corresponding projections for

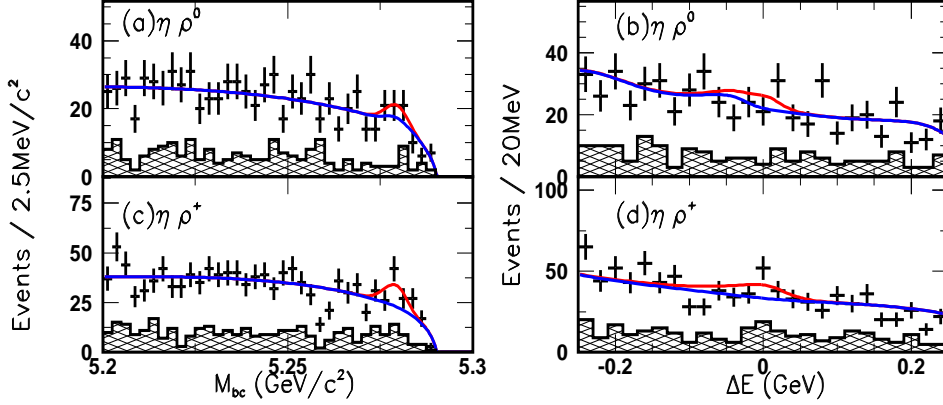


FIG. 2: Projections on M_{bc} and ΔE from 2-D ML fitting results for $\eta\rho^0$ (a,b) and $\eta\rho^+$ (c,d) with the expected signal and background function overlaid. The shaded area represents $\eta \rightarrow \pi^+\pi^-\pi^0$ decays.

the $B \rightarrow \eta\rho$ decays. For $B^+ \rightarrow \eta\rho^+$ decays, where a clear excess is seen, we examine the properties of the ρ^+ candidates. Although statistically limited, clear ρ^+ mass peaks and a polarized $\cos\theta_{\text{hel}}$ distribution are observed (Fig. 3) and are consistent with the expectation from $\eta\rho^+$ with no significant non-resonant $B^+ \rightarrow \eta\pi^+\pi^0$.

SYSTEMATIC ERROR

Systematic errors arise from efficiency corrections and fitting. The main sources of uncertainties in the efficiency corrections are from the reconstruction of low-momentum charged tracks, low-energy photon finding, and \mathcal{LR} cut efficiency, each at a level of a few per cent. The systematic errors include contributions of 1% for \mathcal{LR} cuts, 1% per reconstructed charged

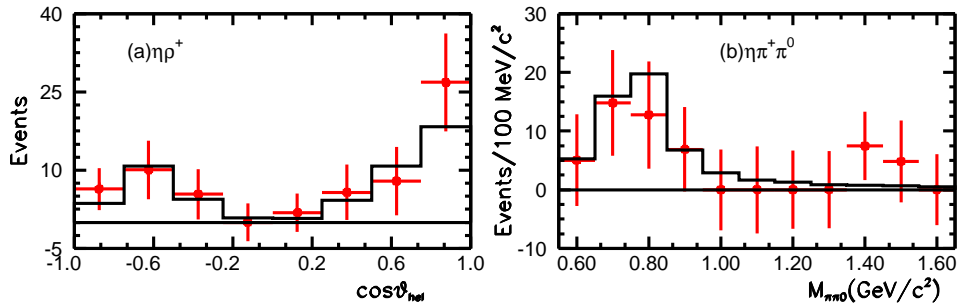


FIG. 3: Fitted yields vs (a) ρ^+ helicity, (b) $\pi^+\pi^0$ invariance mass from $B \rightarrow \eta\rho^+$ decays. The overlaid histograms are expected distributions from MC and normalized by the 2-D fit results.

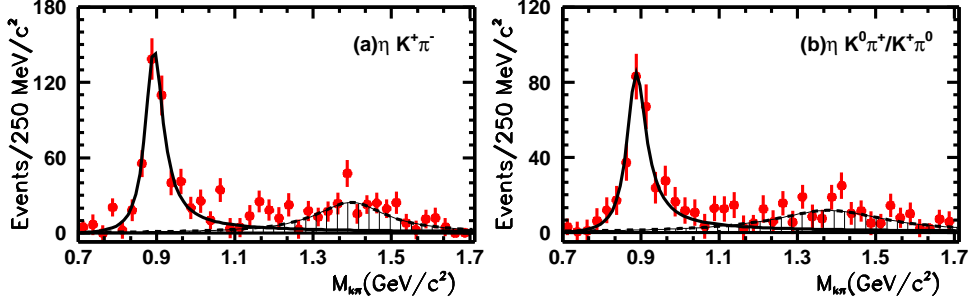


FIG. 4: Fitted yields vs the $K\pi$ invariant mass for the (a) K^{*0} and (b) K^{*+} modes. Overlaid functions are results from fitting with a K^* line shape and a higher resonance. Only the parameters of the higher resonance are free during the fit.

particle, 0.5% for each charged particle identification, 4% for π^0 reconstruction, 4.5% for K_S^0 reconstruction, and 2% for η reconstruction with $\eta \rightarrow \gamma\gamma$. To evaluate a possible non-resonant or higher resonance contribution in the K^* region, we perform a 2D ML fit within different $K\pi$ invariant mass region from 0.7 GeV/ c^2 to 1.72 GeV/ c^2 . Figure 4 shows our results with a K^* line shape and a higher resonance overlaid with the K^* area fixed. Based on this study, the non-resonant $K\pi$ contributions are $1.7 \pm 0.5\%$ for ηK^{*0} and $3.7 \pm 2.0\%$ for ηK^{*+} decays. These corrections will be applied to the final branching fraction measurements of $B \rightarrow \eta K^*$. Due to the limited statistics for $B^+ \rightarrow \eta \rho^+$ decays, a larger systematic error for the non-resonant or higher resonance contributions is assigned with no corrections applied.

We use $B^0 \rightarrow \bar{D}^0 \pi^+$ decays to estimate the uncertainties in the signal function PDF's used for fitting M_{bc} and ΔE by comparing the mean and the width of the M_{bc} and ΔE distributions between the $B^0 \rightarrow \bar{D}^0 \pi^+$ data and the MC sample. For MC estimated $b \rightarrow c$ and charmless B decay backgrounds, we vary the estimated yields by 50% and refit the data. The difference in the fit yields from the nominal values contributes to the systematic error. The overall relative systematic errors are 5.8% for ηK^{*0} , 7.2% for ηK^{*+} , 22% for $\eta \rho^0$ and 8.4% for $\eta \rho^+$.

\mathcal{A}_{CP} MEASUREMENTS

We measure \mathcal{A}_{CP} in the decays of $B \rightarrow \eta K^*$ and $B^+ \rightarrow \eta \rho^+$. Due to the wrong-tag fraction w , the value of \mathcal{A}_{CP} is not the same as the measured values \mathcal{A}_{CP}^{obs} . Their correlation is $\mathcal{A}_{CP}^{obs} = (1 - 2w)\mathcal{A}_{CP}$. In the decay modes we study, only those in which \mathcal{A}_{CP} values are determined by low momentum charged pions will have a non-negligible w . The wrong-tag fractions for $K^{*+} \rightarrow K^0 \pi^+$ is $\sim 1.5\%$ for ηK^{*+} decays and $\sim 2.0\%$ for $\eta \rho^+$ decays. Other decays have $w < 0.1\%$. Since the result for ηK^{*+} is obtained from a simultaneous fit to all four sub-decay modes with roughly equal statistics for $K^{*+} \rightarrow K^+ \pi^0$ and $K^{*+} \rightarrow K^0 \pi^+$, the wrong-tag effect for \mathcal{A}_{CP} should be $< 0.7\%$. Thus, there are no wrong-tag fraction corrections for ηK^* decays. For $\eta \rho^+$, 2% is assigned for w .

To incorporate the CP asymmetry in the fit, the coefficients of the signal and continuum background PDFs in the likelihood are modified: $N_S \rightarrow \frac{1}{2}N_S(1 - q\mathcal{A}_{CP}^{obs})$ and $N_B \rightarrow \frac{1}{2}N_B(1 - q\mathcal{A}_{CP,qq})$, where $q = +1(-1)$ for a $B(\bar{B})$ meson tag and $\mathcal{A}_{cp}^{obs}, \mathcal{A}_{cp,qq}$ are the \mathcal{A}_{cp} outputs for

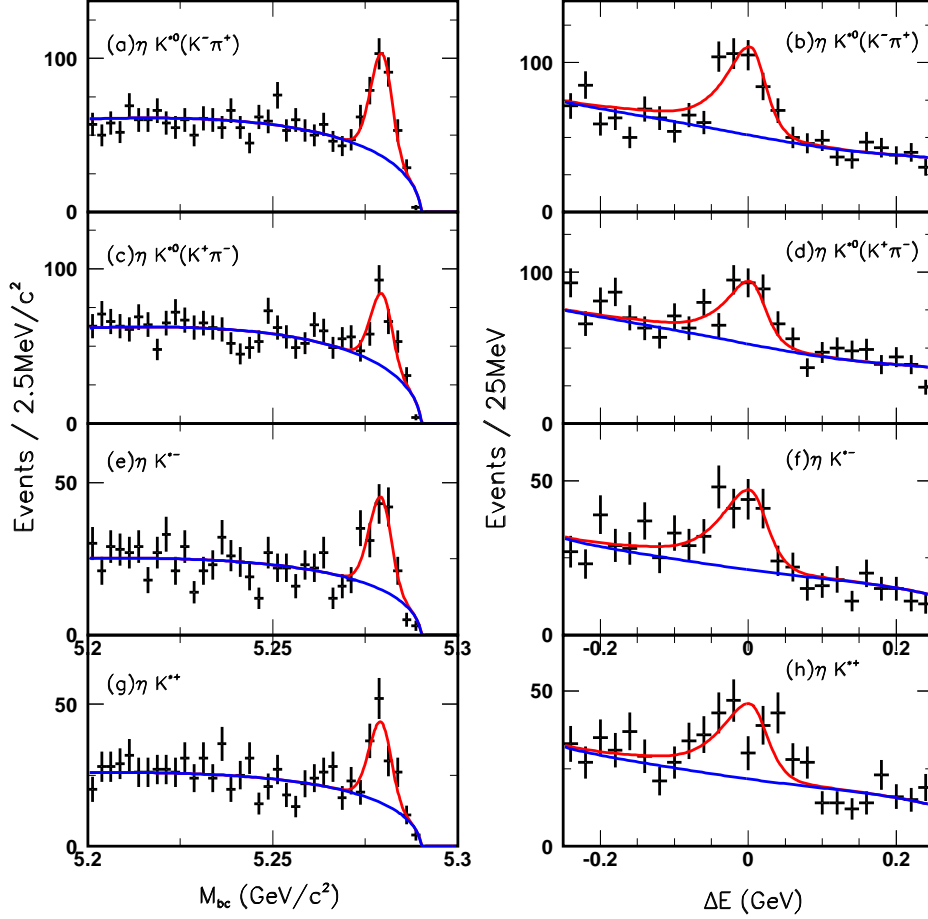


FIG. 5: Projection on M_{bc} (left) and ΔE (right) from 2-D ML fitting results for ηK^* with the expected signal and background function overlaid. Figures (a,b,e,f) are for \bar{b} decays and (c,d,g,h) are for b decays.

signal and continuum respectively. The results are $\mathcal{A}_{cp}^{obs}(\eta K^{*0}) = 0.17 \pm 0.08$, $\mathcal{A}_{cp}^{obs}(\eta K^{*+}) = 0.03 \pm 0.10$ and $\mathcal{A}_{cp}^{obs}(\eta \rho^+) = -0.04^{+0.34}_{-0.32}$. Figure 5 shows the projections of the data and the fits onto M_{bc} (for events in ΔE signal slice) and ΔE (for events in the M_{bc} signal slice) for the $B \rightarrow \eta K^*$ decays.

Since the systematic errors in η reconstruction and the number of $B\bar{B}$ events cancel in the ratio, the systematic uncertainty of \mathcal{A}_{cp} is mainly from the asymmetry for PID of charged kaons and the fitting PDF's. The efficiency asymmetry for the PID of charged kaons is 0.01 in absolute value.

DISCUSSION AND CONCLUSION

In summary, we report measurements of the exclusive two-body charmless hadronic $B \rightarrow \eta K^*$ and $B \rightarrow \eta \rho$ decays with high statistics. Our results confirm that the branching

fractions for $B^0 \rightarrow \eta K^{*0}$ and $B^+ \rightarrow \eta K^{*+}$ are large and are consistent with previous measurements [4, 19]. The branching fractions obtained are $\mathcal{B}(B \rightarrow \eta K^{*0}) = (15.9 \pm 1.2 \pm 0.9) \times 10^{-6}$, and $\mathcal{B}(B \rightarrow \eta K^{*+}) = (19.7^{+2.0}_{-1.9} \pm 1.4) \times 10^{-6}$, where the first error is statistical and the second systematic. Our measurements imply that the branching fraction of $B^+ \rightarrow \eta K^{*+}$ is 1σ higher than $B^0 \rightarrow \eta K^{*0}$, which may constrain the contribution of the flavor singlet penguin amplitude as suggested by various theorists [8, 9]. Large signals of $B^+ \rightarrow \eta \rho^+$ have been observed with the branching fraction $\mathcal{B}(B \rightarrow \eta \rho^+) = (4.1^{+1.4}_{-1.3} \pm 0.34) \times 10^{-6}$. The branching fractions and 90% C.L. for $B^0 \rightarrow \eta \rho^0$ decays are $\mathcal{B}(B^0 \rightarrow \eta \rho^0) = (0.84^{+0.56}_{-0.51} \pm 0.18) \times 10^{-6}$ ($< 1.9 \times 10^{-6}$).

We also search for direct CP asymmetry in $B \rightarrow \eta K^*$ and $B^+ \rightarrow \eta \rho^+$, and final results are consistent with no asymmetry. The results are: $\mathcal{A}_{cp}(\eta K^{*0}) = 0.17 \pm 0.08 \pm 0.01$, $\mathcal{A}_{cp}(\eta K^{*+}) = 0.03 \pm 0.10 \pm 0.01$, and $\mathcal{A}_{cp}(\eta \rho^+) = -0.04^{+0.34}_{-0.32} \pm 0.01$.

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